

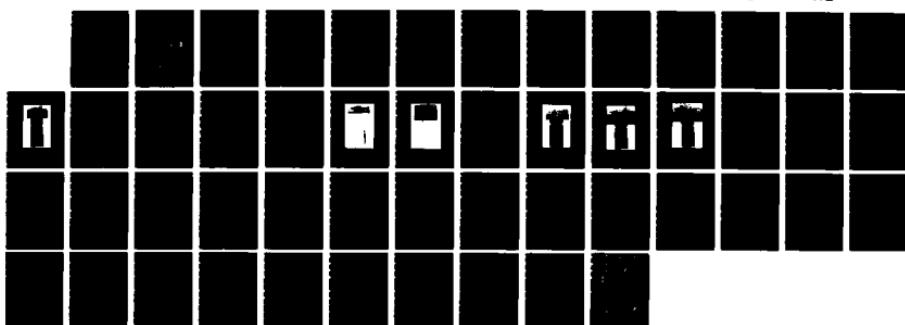
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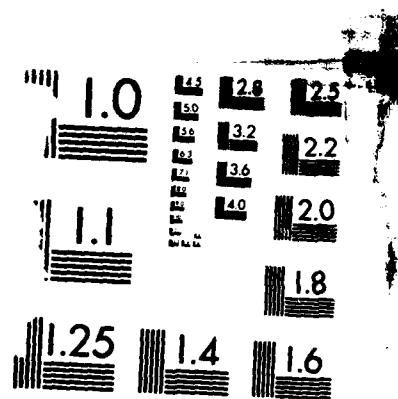
EVALUATION OF SURFACTANTS FOR PHYSICAL DECONTAMINATION 1/1  
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## Evaluation of Surfactants for Physical Decontamination in Spray Applications

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<p>→ Using a low pressure spray, the effectiveness of commercially available surfactants in removing a thickened mustard simulant from a low and a high energy surface was determined in a series of laboratory bench scale tests. The objective of this investigation was to recommend suitable decontamination (decon) candidates for larger scale field tests. The test method involved a recycling flow system and a UV-VIS double-beam spectrophotometer which monitored the amount of simulant removed. The spectrophotometer was interfaced with a computer for data collection. Because of light scattering problems, due to bubbles in the flow system, surfactant effectiveness data were based on a visual method of detection.</p> <p>The effectiveness of the decon test fluid appears to be specific for the type of substrate, the contaminant and the aqueous medium employed. On a high energy surface (stainless steel), tap water and synthetic seawater were as effective as an automatic dishwashing detergent in removing thickened methyl salicylate. However, on a low energy surface (Teflon), surfactants that exhibited a combination of increased wetting, emulsification, and solubilization</p>			
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properties removed the thickened simulant more effectively than water. These include sodium dioctyl sulfosuccinate (1% in tap water), sodium dihexyl sulfosuccinate (1.6% in tap water), and Aqueous Film Forming Foam (AFFF - 3% dilution in tap water and in synthetic seawater). Also, under the same test conditions, the removal times of these surfactant "solutions" were within 1-3 minutes, whereas that of water was > 15 minutes for complete removal of the thickened simulant from the Teflon surface. *Keywords: ~~per John Baldwin~~*

*per John  
Baldwin*

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## EVALUATION OF SURFACTANTS FOR PHYSICAL DECONTAMINATION IN SPRAY APPLICATIONS

### INTRODUCTION

The use of chemical and biological warfare (CBW) agents in military combat operations threatens the lives of the crew and the accomplishment of the mission. Thus, a vital need exists for effective decontamination of personnel, equipment and affected areas.

Decontamination (decon) methods may be physical or chemical in nature. Physical decon involves "removal only" of the simulant/agent via aqueous and non aqueous systems. In contrast, chemical methods involve detoxification/neutralization reactions, i.e., chemical conversion of the simulant/agent to less toxic and preferably non toxic compounds via hydrolysis, oxidation, etc. In this report, physical decon involving an aqueous medium was investigated using various types of commercially available surfactants. A method was also developed to evaluate the effectiveness of the surfactants in specific simulant/substrate systems.

Effective methods of physical decontamination, involving an aqueous medium, which have been reported are consistent with the fact that mechanical action is a key factor in a cleaning process<sup>1</sup>. The role of detergents, however, is considered to either reduce the work requirement, or increase the efficiency with which mechanical energy is utilized in the cleaning process<sup>2</sup>. Thus, at very high spray or jet pressures (1000<sup>3a</sup> to 3000<sup>4</sup> psi), water at ambient temperature is an effective decontaminant; whereas at lower pressures (110 psi)<sup>5</sup>, or much lower<sup>6</sup> (value not given), water or steam is inadequate. The study of surfactants via sprays<sup>7</sup> as well as drop spreading tests<sup>8</sup> has demonstrated the potential of a fluorosurfactant and a betaine surfactant as effective decontaminants.

In this report, surfactant effectiveness was evaluated using a low pressure spray (~5 psi) via a series of bench tests. These bench scale spray applications serve as a practical method of studying decontamination and offer better control of the independent variables as compared with larger scale field tests. The use of a low pressure spray also minimizes the contribution of mechanical energy in the decontamination process, thereby providing more accurate evaluations of surfactant effectiveness. Moreover, challenging simulant/contaminant-substrate systems were

selected e.g., a high density application (~12 times a likely threat concentration) of methyl salicylate (a simulant for mustard)<sup>3b</sup>, thickened to a viscosity of ~5 times the standard for thickened CW agents, on a low energy surface (Teflon). The method used for evaluating decon candidates involved a recycling flow system and a UV detector. However, the problem of bubbles in the flow system has limited the use of a flow cell in the detector. Thus, a visual method of detection involving the use of an oil soluble dye (incorporated in the thickened methyl salicylate/contaminant formulation) was also employed.

This report focused on the removal of thickened methyl salicylate from a low energy surface (Teflon), since preliminary studies indicated that a high energy surface (stainless steel) was not a challenging substrate: water was found to be an effective decon fluid for the removal of the thickened simulant from a stainless steel substrate. Various types of commercially available surfactants were evaluated using tap water and in specific cases, synthetic sea water as the references. Surfactant systems were considered promising on the basis of short removal times (~ 3 mins or less). In addition to evaluating the various surfactants, possible mechanisms that may be involved in the removal process were also discussed.

## EXPERIMENTAL

### Materials

#### *Simulant/Contaminant*

**Simulant:** Colored thickened methyl salicylate (MST-D) Methyl salicylate (Fisher Scientific Co.) is a well-known simulant for mustard. The solubility and surface active properties of mustard and methyl salicylate, shown in Table 1, indicate that methyl salicylate is also a good mustard simulant for physical decontamination studies involving an aqueous medium.

**Thickener:** K-125 (Rohm and Haas) is a co-polymer consisting of the following monomers viz., methyl methacrylate, ethyl acrylate, and butyl acrylate.

**Dye:** Celanthrene Brilliant Red (E.I., duPont de Nemours and Co., Inc.) is oil soluble.

#### *Preparation of Colored Thickened Methyl Salicylate*

K-125 (~1.89 g) was added gradually to methyl salicylate (25 g). The mixture was stirred and gently heated over a warm water bath, both during and after the addition until the K-125 was completely dissolved.

The viscosity of the resultant clear thickened liquid (5038 centistokes) was measured using a Cannon-Manning capillary viscometer (400 A25, constant 1.197). The thickened methyl salicylate was colored wine red by adding a very small amount of Celanthrene Brilliant Red dye.

**Contaminant:** Pennzoil 705 (Pennzoil Products Co.), a multi-purpose lubricant is a lithium soap grease. It was colored dark pink by adding a small amount of Celanthrene Brilliant Red dye. This grease was selected to represent a worse case contaminant because of its very high viscosity and relatively non polar characteristics.

### *Surfactants*

Various types of commercially available surfactants were screened. Mainly nonionic samples were supplied by surfactant manufacturers, in response to a request for surfactants which exhibit the following properties:

- a. Excellent wetting and emulsification properties for the removal of a thickened polar oil type material from a Teflon surface
- b. Soluble or fairly soluble in water

The surfactants evaluated included 5 anionics, 2 cationics, 12 nonionics, and 4 blends of anionic and nonionic surfactants. The anionic and nonionic surfactants and their respective manufacturers are listed in Tables 2-5, according to their ionicity and class of compounds. Their solubility properties and manufacturers' recommended applications are also included where available. The cationics and blends of anionic and nonionic surfactants are likewise described below:

#### *Cationics (I.C.I. Americas Inc.)*

N-substituted-N-ethyl morpholinium ethosulfate

*G-263:* N-cetyl-N-ethyl morpholinium ethosulfate - 35% aqueous solution; soluble in water and in xylene at 10% concentration.

*G-271:* N-soya-N-ethyl morpholinium ethosulfate - 35% aqueous solution; soluble in water and in xylene at 10% concentration.

#### *Blends of Nonionic and Anionic Surfactants*

*AFFF* (Aqueous Film Forming Foam) is a formulated product containing a mixture of fluorocarbon surfactants and hydrocarbon surfactants. Further information on its formulation is proprietary. It is manufactured by 3 Companies viz. National Foam System Inc., The Ansul Co., and 3M Co.

AFFF is available both as a 3% and a 6% concentrate (v/v). According to the manufacturers, the 3% concentrate is twice the concentration of the 6% concentrate. In these investigations, AFFF was used at a 3% dilution level (manufacturer's term for a 3% dilution of a 3% concentrate). AFFF is soluble in water, and is recommended in firefighting systems because of its stable high foam and its spreading characteristics.

#### *Bio-Soft HD-100 (Stepan Co.)*

Information on its formulation is proprietary. However, Stepan Co., describes this product as a "unique blend of nonionic and anionic surfactants that makes it an excellent starting point for the formulation of high quality liquid laundry syndets." It is water soluble.

#### *Preparation of Surfactant 'Solutions' (g w/v in liter)*

To prevent gelling of the surfactant, 'solutions' were prepared by adding a known weight of the surfactant to water with stirring, until dissolution was complete.

#### **Apparatus**

A schematic diagram of the decon spray system is shown in Figure 1. The test material (actual test surface, ~14 cm long - see Procedure) was suspended vertically inside the decon tank at a distance from the nozzle (~ 13.5 cm) that would allow the effluent washings to fall directly into the reservoir of surfactant test fluid. The decon tank (a glass fish tank: 50.5 cm long x 31 cm high x 26 cm wide) was elevated at a 30° angle (not shown) to facilitate mixing of the stirred surfactant test fluid (1 liter).

The stirred test fluid was drawn from the tank by a stainless steel vane pump (Eastern Industries model VW-1) which was driven by an electric motor (General Electric, 1/15 HP, 5000 rpm, 115 V). The fluid flowed through the pump and was split into 2 streams. The pressure of the flow to the nozzle (Spraying Systems: full cone tip, orifice diameter .030 inch) was monitored by a pressure gauge. The rate of the flow diverted to the detector was monitored with a flowmeter (Brooks Rotameter Co., stainless steel float in tube 6-15-2). Both the pressure and flow rate could be varied via a by-pass valve or pump motor speed control (General Radio Co., Variac) or both. The detector, a UV-Visible double-beam spectrophotometer (Perkin Elmer Lambda 3A) was interfaced with a computer. Thus, the simulant concentration (via its absorbance measurements), and the nozzle pressure could be monitored during the decontamination process. However, problems of light scattering due to bubbles in the flow system has limited the usefulness of this automated method of monitoring surfactant effectiveness (see Detection Methods).

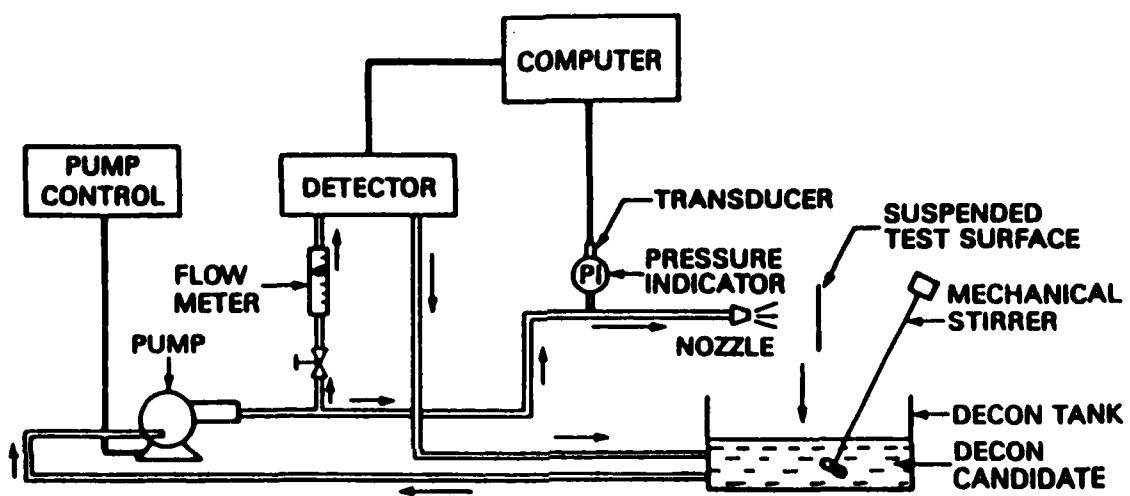


Figure 1 - Schematic diagram of the decon spray system

## Procedure

Colored thickened methyl salicylate (~5038 centistokes) - referred to as MST-D, was spotted (drop diameter ~2-3 mm) on a smooth substrate with a density coverage of ~50 mg over 2 cm x 2 cm area (Figure 2), at the site of the fluid spray impact. Removal of the applied thickened simulant/contaminant from the test surface was examined using a low pressure spray (~5 psi) of the test fluid and a flow rate of ~600 mL/min. To avoid cross contamination between evaluations, the tank and the entire flow system were thoroughly cleaned by pumping water through the system before each evaluation. The tank was considered clean when no foam was present.

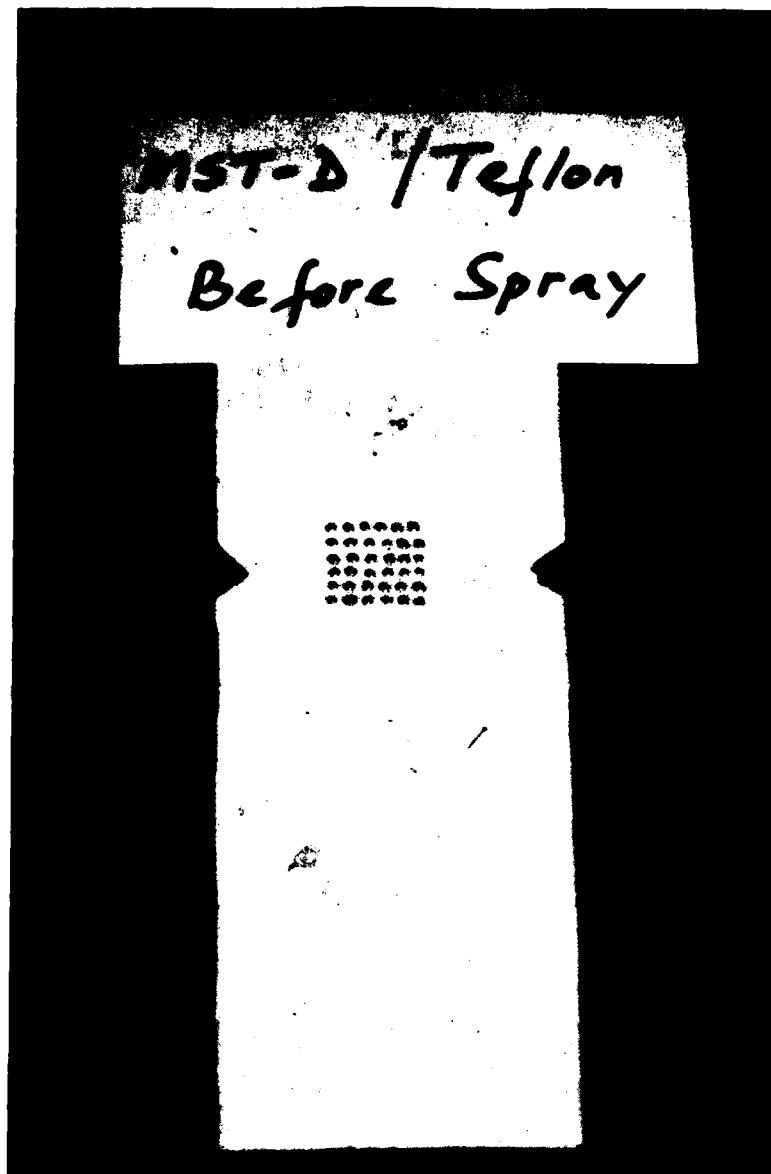
The test surface included the origin of application (~2 cm length) plus an additional 12 cm vertical length of test surface prior to the effluent washings falling into the decon tank. Effectiveness of the test fluid was determined via two detection methods viz., UV spectrophotometry and a visual method. These methods are subsequently discussed.

## Detection Methods

### *UV Spectrophotometry*

This method determines the concentration of methyl salicylate present in the effluent washings via its absorbance measurements. Thus, using a quartz flow cell (Helma, 2 cm path length), in the sample beam, and a regular quartz cell containing the surfactant solution in the reference beam, absorbance measurements were made at 304 nm i.e., the wavelength of maximum absorbance for methyl salicylate. As shown in Table 6, the absorbance of methyl salicylate increased with increasing time to a maximum at ~9 min, after which it decreased. The time at which maximum absorbance occurred was used to measure surfactant effectiveness. The decrease in absorbance with time was due to a loss of methyl salicylate via the spray mode. For example, after ~10 min. spray period, ~15% methyl salicylate is lost and ~25% after ~15 min. spray period. Consequently, the accuracy of the absorbance measurements decreases for spray periods > ~10 min. Nevertheless, within a ~10 min. spray period, UV spectrophotometry offers the capability of determining the rate of methyl salicylate removal.

*Limitations:* Table 6 represents surfactant systems in which light scattering did not interfere significantly with the absorbance measurements. However, for systems in which light scattering did interfere, the following problems were encountered:



**Figure 2** - Colored thickened methyl salicylate (MST-D) spotted (~ 2-3 mm diameter) on Teflon: Before Spraying

1. In the determination of surfactant effectiveness, the time at which maximum absorbance occurred was either not definitive (see Table 7) or was erroneous, or both, as compared with a visual detection method.

2. In quantification of the data, poor precision of the maximum absorbance values was obtained for the same MST-D concentration e.g., .594, .756 and 1.389 were the maximum absorbance values for the same concentration of 50 mg MST-D in 1 liter of Aerosol MA-80 (1.6%).

#### *Light Scattering: Causes and Recommendations*

*Causes:* Light scattering was caused by the presence of bubbles in the flow system, as well as by surfactant solutions that were not completely soluble at the concentrations employed. Bubble formation was due to: a) the nature of the surfactant e.g., high foam characteristics; b) stirring the effluent washings -adequate stirring was necessary to facilitate mixing of MST-D in the surfactant; and c) the fast flow rate employed (~600 ml/min.) - this was necessary to improve the sampling accuracy of methyl salicylate in the effluent at known time periods.

It is important to note that high foaming surfactants did not always interfere with the absorbance measurements. Thus, light scattering appears to be due to a combination of the factors mentioned above.

#### *Recommendations:*

1. Use of an integrating sphere in the UV-spectrophotometer would minimize, if not eliminate, scattering due to hazy surfactant solutions.

2. Improve the shape of the reservoir to a round configuration or increase the depth of the reservoir fluid or both. This can be accomplished by the use of 2 blocks placed inside the tank -one on each side. This improvement would facilitate better mixing at lower stirrer speeds and minimize the entrainment of air caused by vortexing. Use of a tachometer would also help to ensure a constant stirrer speed.

3. Use of a flow cell in the reference beam may help to nullify scattering due to the presence of bubbles in the sample flow cell.

4. Use of a de-bubbler device in the flow system should be re-examined even though a preliminary test was inconclusive.

### *Visual Detection Method*

This method involves the use of an oil soluble dye (Celanthrene Brilliant Red), which was incorporated in the thickened methyl salicylate formulation/contaminant. The method thus determines the removal of MST-D/contaminant from the test surface. Using a stop watch, surfactant effectiveness was measured as the time (min.) taken for complete removal of the thickened simulant/contaminant from the entire test surface. This method is a more rigorous test of surfactant effectiveness than UV spectrophotometry, since the latter determines only the concentration of methyl salicylate/simulant removed.

*Advantages of the method are as follows:*

- a. It is independent of light scattering problems caused by bubbles in the flow system and/or hazy surfactant solutions.
- b. It enables problems of redeposition to be readily visualized.
- c. It is accurate and dependable in cases of complete removal.

*Limitations:* Unlike UV spectrophotometry, the rate of removal cannot be determined. This limitation is particularly significant in cases of incomplete MST-D/ contaminant removal from the test surface. Thus the amount removed at a known time period cannot be evaluated.

### *Choice of Detection Method*

Because of the limitations of both methods of detection, and because the two methods complement each other, surfactant effectiveness should be evaluated using both methods simultaneously. However, in order to be consistent in the determination of surfactant effectiveness the surfactants were evaluated and categorized using the visual detection method. When possible, supporting data on the amount of methyl salicylate removed was determined via UV spectrophotometry.

### **Systems Examined**

The following parameters were investigated:

*Substrate:* A high energy surface e.g. stainless steel and a low energy surface e.g. Teflon.

*Simulant/Contaminant (See Materials):* Mainly, colored thickened methyl salicylate (MST-D) was examined. Colored Pennzoil grease was also investigated, and was selected to represent a worse case contaminant.

*Surfactants (See Materials):* These included various types of commercially available anionic, cationic, and nonionic surfactants as well as blends of anionics and nonionics. Unless otherwise stated, the concentration (w/v) of the surfactants evaluated was above their critical micelle concentration (cmc) level, thereby optimizing their wetting properties.

*Aqueous Medium:* The surfactant solutions were usually prepared in tap water. In a limited number of experiments however, synthetic sea water was also used. Thus, tap water or synthetic sea water was employed as the reference, depending on the aqueous medium used to prepare the surfactant solutions.

*Spray Temperature:* Unless otherwise stated, the spray temperature employed was ~21°C.

*Effect of Ionicity, Concentration, and Spray Temperature of the Surfactant:* Results of this investigation were presented<sup>9</sup> recently. Nevertheless, these experiments are redescribed in this report for purposes of completeness. In this investigation, the most promising anionic surfactant (Aerosol GPG), and an effective nonionic surfactant (Renex 678) were screened using a 2<sup>3</sup> factorial design<sup>10</sup> (see Table 8), in the removal of MST-D from a Teflon substrate. Renex 678 was selected in preference to Renex 30 because of its higher cloud point. Tap water was used as the reference.

## RESULTS AND DISCUSSION

### General Screening

Surfactant effectiveness was evaluated with reference to water in the removal of a colored thickened simulant for mustard. The colored thickened methyl salicylate is referred to as MST-D. These evaluations were performed using a low pressure spray (~5 psi) directed at the origin of the MST-D application. The effectiveness of the test fluid was measured as the time (min.) required for ~100% removal of MST-D from the entire test surface, and was based on the visual method of detection (see Experimental - Choice of Detection Methods). Results of the various parameters investigated are subsequently described, and possible mechanisms are discussed.

## **Effect of Substrate**

### ***Stainless Steel***

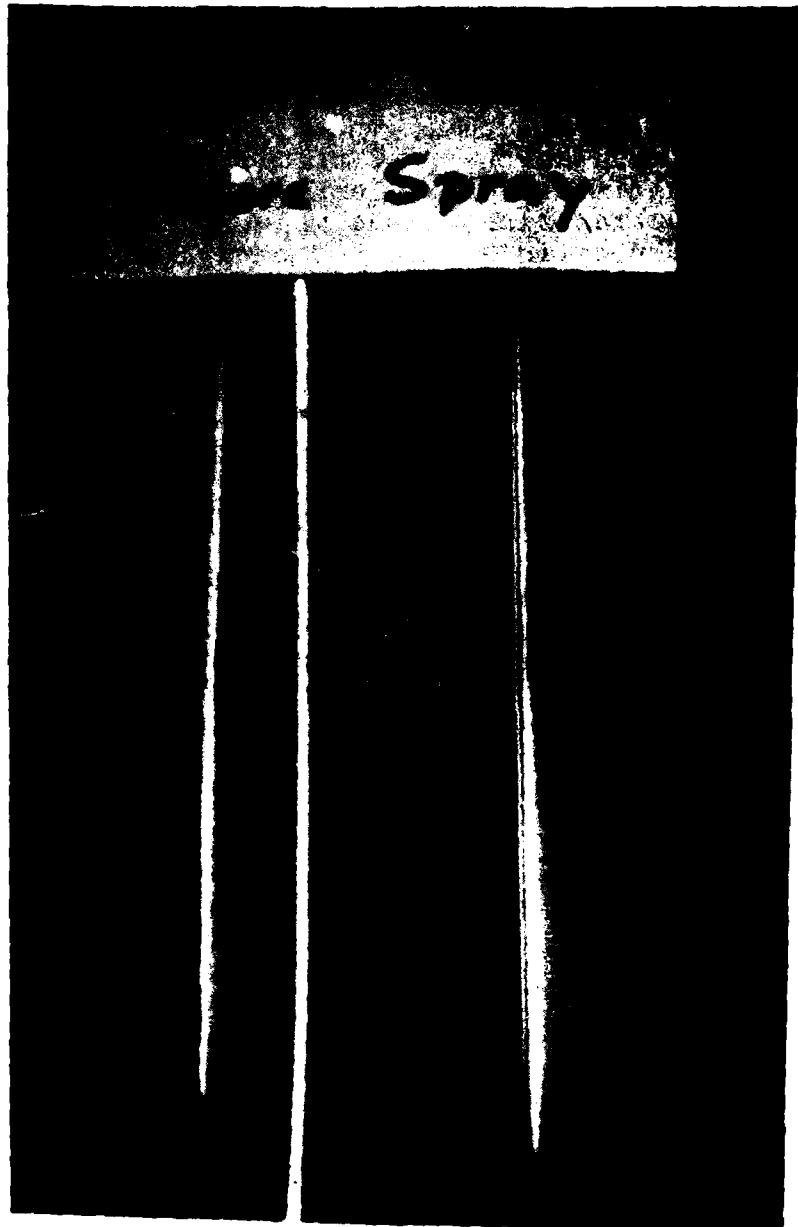
#### *Evaluation*

As shown in Table 9, on a stainless steel substrate, water was more effective than most of the surfactants evaluated in the removal of MST-D from the entire test surface. Furthermore, White Magic, a formulated automatic dishwashing detergent was only ~ 10-25% more effective than water. Thus, on a stainless steel substrate, fresh and seawater appear promising as decon candidates with a thickened mustard simulant. The relatively poor performance of the surfactants versus water indicates that for the removal of this specific simulant from a high energy surface (stainless steel), detergency mechanisms do not play a major role. For example, the surfactants that exhibit better wetting properties (i.e. lower surface tension and lower interfacial tension) and better emulsification properties (lower interfacial tension and high hydrophile lipophile balance (HLB) values: ~14-20) exhibited longer removal times than water.

#### *Mechanism*

Although the detergency mechanisms that are operative in laundering are well established, the detergency mechanisms involving spray applications (e.g., automatic dishwashing) are only poorly understood<sup>b</sup>. A possible explanation for the greater effectiveness of water (i.e., versus the surfactants) on a stainless steel substrate may be related to the high adhesional properties of a high energy surface. That is, the extent of wetting/spreading of the thickened simulant/contaminant on a high energy surface will be greater than on a low energy surface such as Teflon. Thus, on impact of the water-spray, the MST-D droplets are flattened into thinner films, and the mechanical energy required for their removal is thus reduced.

In contrast, the excellent wetting properties of the surfactants facilitate displacement of the MST-D droplets into thicker films. Consequently, the mechanical energy required for MST-D removal is increased, thereby resulting in the decreased performance of the surfactants. Formation of thicker films which redeposited was observed particularly with AFFF. (cf. Figs. 3 and 4). Furthermore, the high foam characteristics of AFFF would also lower the impact energy of the spray, thereby contributing to the increased removal time. For similar reasons, automatic dishwashing formulations employ low foaming or defoaming surfactants<sup>c</sup>.



**Figure 3 - Colored thickened methyl salicylate (MST-D) spotted (~ 2-3 mm diameter) on stainless steel: Before Spraying**

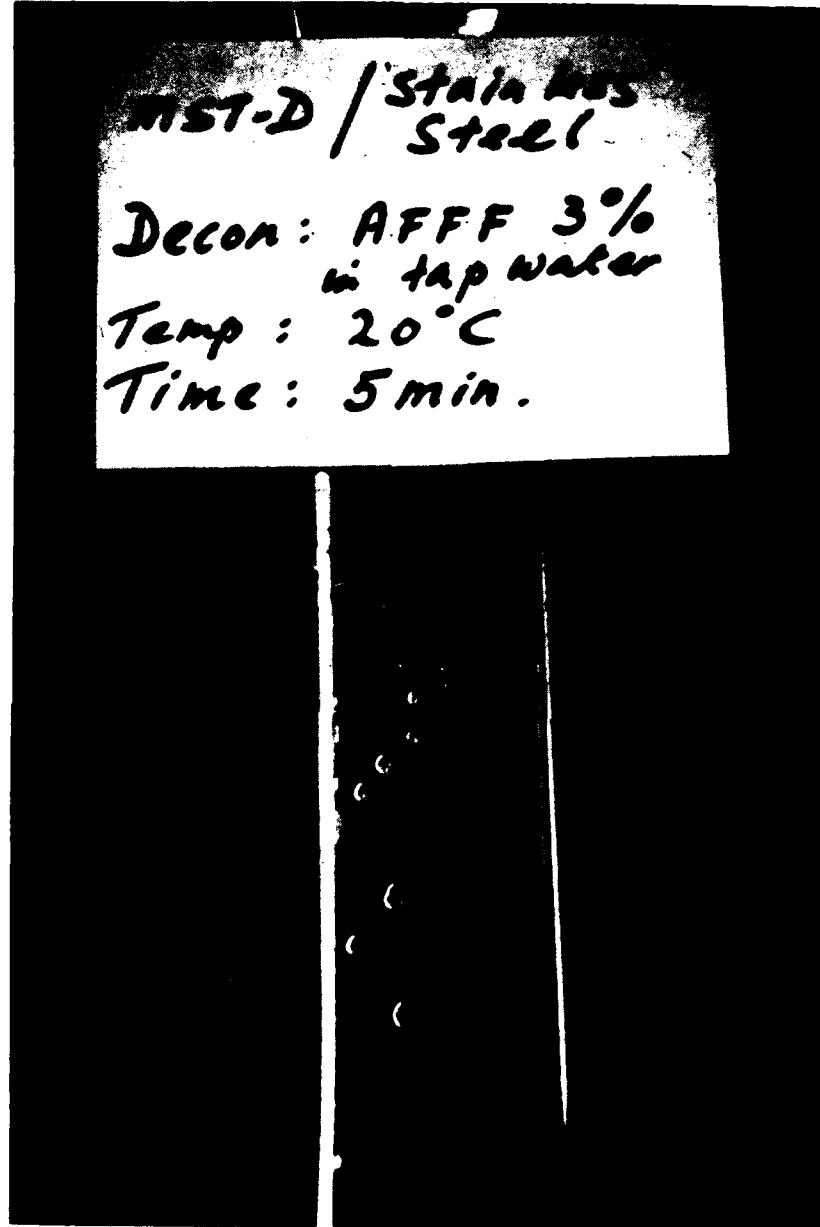


Figure 4 - Stainless steel substrate: Larger MST-D droplets formed after spraying with 3% AFFF/5 min

## **Teflon**

### **Evaluation**

Since water appears to be an effective decon fluid for the removal of a thickened mustard simulant on a high energy surface (stainless steel), a low energy surface (Teflon) was subsequently examined. For a Teflon substrate, the evaluation of various types of commercially available surfactants indicated three levels of surfactant effectiveness relative to water. Based on the level of surfactant effectiveness during a maximum spray period of 15 minutes, the surfactants were categorized into the following three classes.

*Class A:* Surfactants which performed better than water and were effective in ~100% removal of MST-D from the entire test surface. These included anionics, cationics, nonionics, and a blend of anionics and nonionics (see Table 10).

*Class B:* Surfactants which performed better than water in the removal of MST-D from the origin of application (cf Fig. 5 and Fig. 6). However, these surfactants were not effective in the removal of MST-D from the entire test surface during the 15 minute spray period. Removal from the origin was due to a combination of actual MST-D removal as well as a mere downwards movement of MST-D via elongation of MST-D droplets into threads. These surfactants exhibited varying removal times from the origin of application as well as varying amounts of redeposition (see Fig. 6). This class of surfactants included: anionics, nonionics and a blend of nonionic and anionic surfactants (see Table 11).

*Class C:* Surfactants which performed similar to or worse than water in the removal of MST-D from the origin of application. These included various nonionics (see Table 12, also Fig. 7). However, based on UV absorbance data, these surfactants removed comparable amounts of methyl salicylate relative to water (cf Table 13 with Table 14).

### **Promising Decon Candidates**

The surfactants in Class A (Table 10) were considered to be promising decon candidates with a thickened mustard simulant, on the basis of short removal times i.e., ~3 minutes or less. Consequently, only the anionics and blends of anionic and nonionic surfactants qualify as promising candidates. Of the anionic surfactants, the most promising was sodium dioctyl sulfosuccinate i.e., Aerosol GPG and Triton GR-5M (removal time, 1 min) at 1% concentration in tap water. However, Aerosol MA-80 (1.6% in tap water) also appears to be very effective (removal time, 1.5 min).

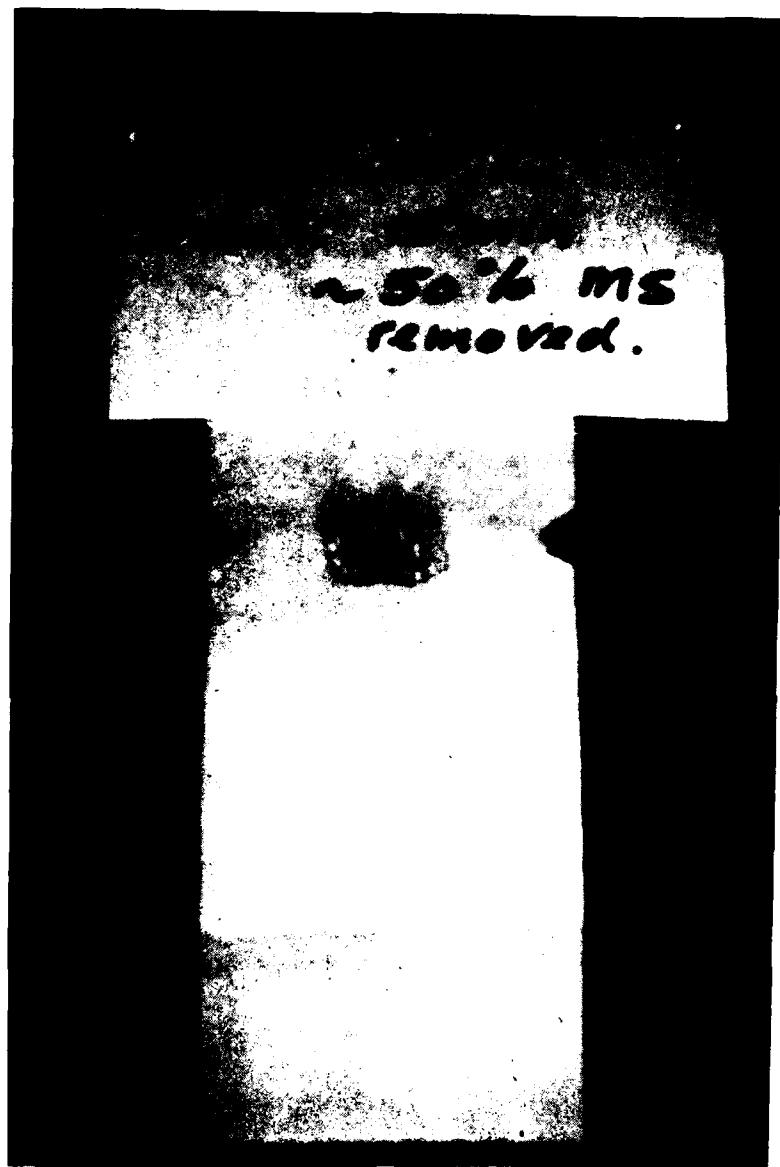


Figure 5 - Teflon substrate: Residual MST-D at the origin of application after spraying with water/15 min

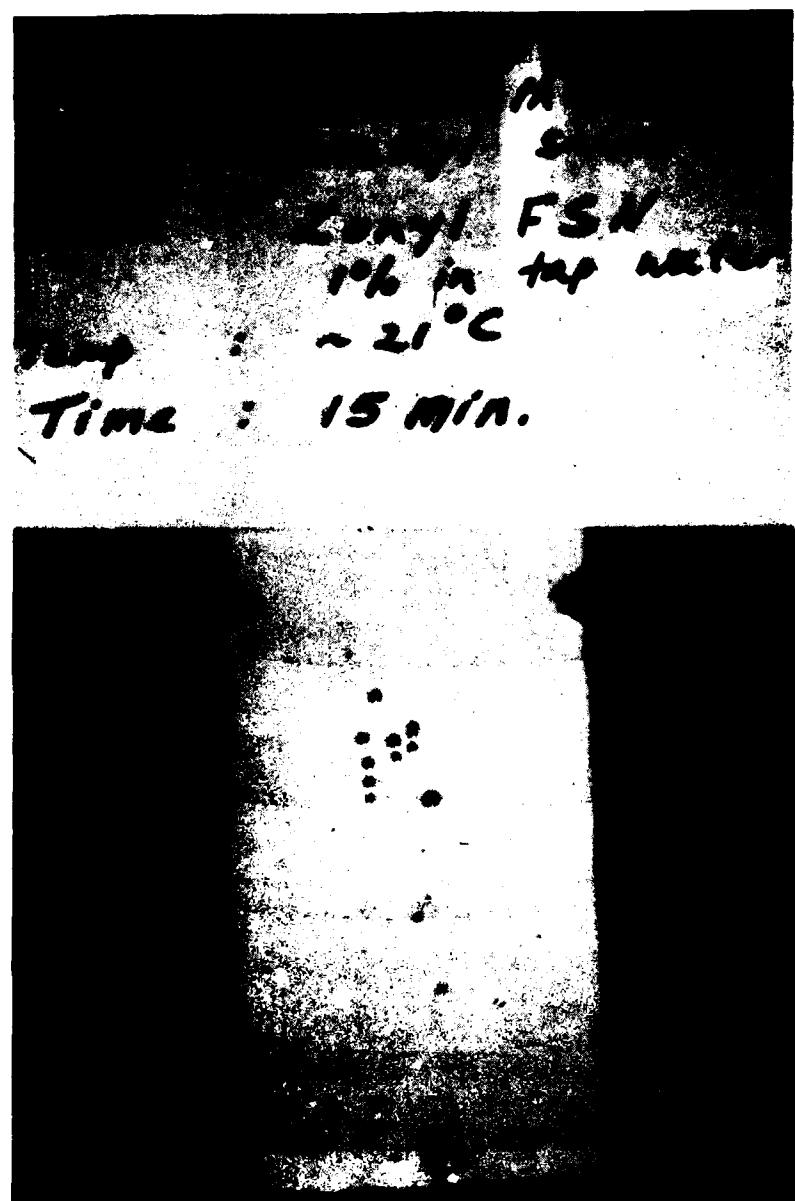
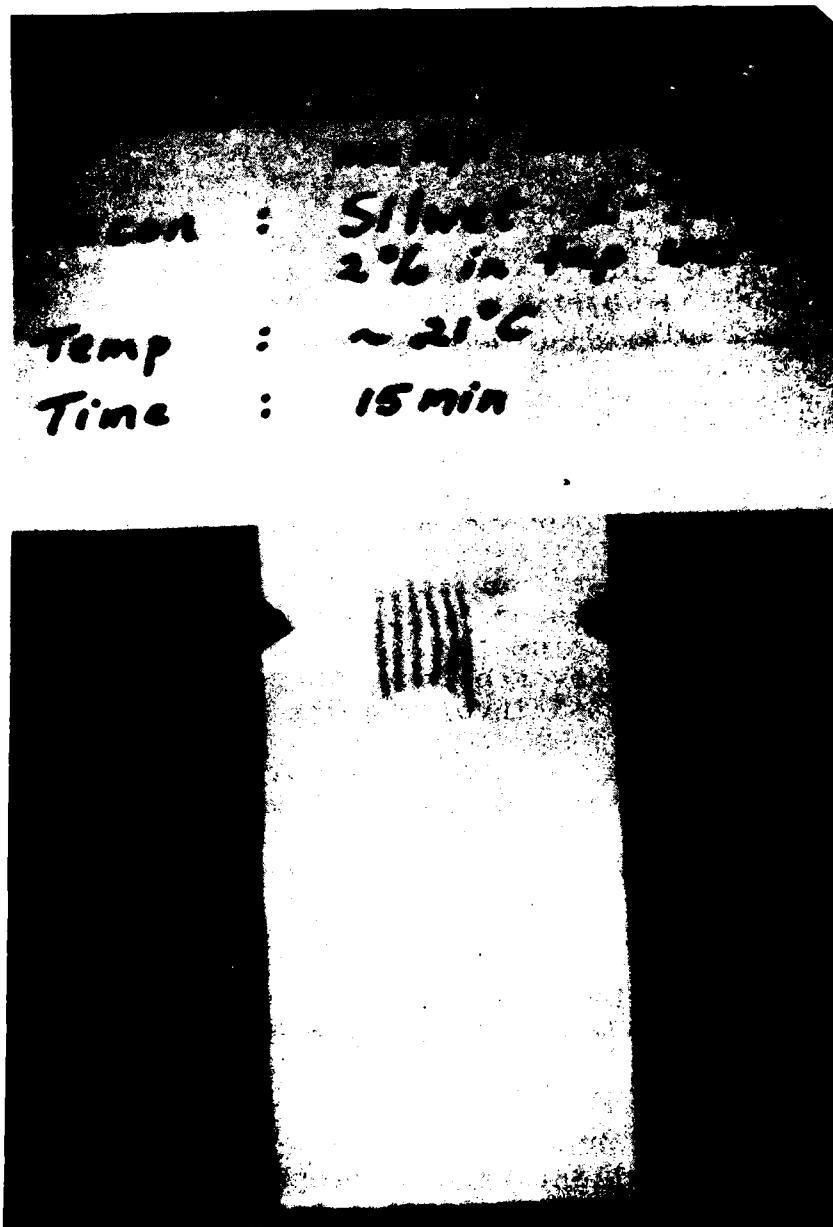


Figure 6 - Teflon substrate: Residual MST-D showing redeposition after spraying with Class B surfactant, Zonyl FSN, for 15 min



**Figure 7 - Teflon Substrate: Residual MST-D at the origin of application after spraying with Class C Surfactant, Silwet L-7607 for 15 min**

The AFFF blends although promising at the 3% dilution level (see Experimental - Materials), were ~ three times less effective than Aerosol GPG or Triton GR-5M in tap water. However, no significant differences in surfactant effectiveness were observed among the three brands of AFFF. Nevertheless, significant differences have been reported<sup>11</sup> in the extent of nonreactivity/compatibility among the various brands of AFFF in buffered hypochlorite solutions i.e., Ansul > 3M > National.

#### *Mechanism*

##### *Good Correlation with Surfactant Properties:*

On comparison of the surfactants in Class A, an apparent correlation of surfactant effectiveness with the listed surfactant properties was observed between certain anionics and certain nonionics (see Table 10). Thus, an approximate ninefold increase in surfactant effectiveness of the most effective anionic surfactant (Aerosol GPG or Triton GR-5M) versus the most effective nonionic surfactant (Renex 30, 2%), may well be related to a combination of: lower surface tension, lower interfacial tension, faster rate of wetting and higher HLB value of the anionic surfactants. However, an approximate threefold decrease in surfactant efficacy of AFFF vs Aerosol GPG or Triton GR-5M, despite AFFF's much lower surface tension may be related to the high foam characteristics of AFFF. As alluded to earlier (Stainless Steel, Mechanisms), high foaming lowers the impact energy of the spray. Nevertheless, these results support a detergency mechanism<sup>12-14</sup> involving the following:

1. Progressive displacement of MST-D/contaminant molecules by more strongly adsorbed surfactant molecules (rolling-up-process). This is accomplished by those surfactants that lower the work of adhesion between MST-D/ contaminant and the Teflon substrate. Thus, as shown by Dupre's equation for a low energy surface<sup>15a</sup>

$$W_A = \gamma_{IFT} (1 + \cos \theta)$$

where  $W_A$  is the work of adhesion,  
 $\gamma_{IFT}$  is the interfacial tension, and  
 $\theta$  is the contact angle.

the work of adhesion is lowered by surfactants that exhibit excellent wetting properties i.e., low surface tension and low interfacial tension. Since the rate of lowering of these properties (i.e., the rate of wetting) is also important<sup>16a</sup>, this factor would be particularly relevant in dynamic modes such as spray applications.

2. Emulsification of the MST-D contaminant: Emulsification disperses the contaminant (non polar) as globules which are easily dislodged from the substrate after the rolling-up process<sup>12a</sup>. Furthermore, dispersion of the

globules as a fairly stable emulsion would prevent problems of redeposition<sup>12b</sup>. Ease of emulsification is facilitated by surfactants that exhibit low interfacial tensions<sup>15b,16b</sup>, and HLB values within the range ~ 8-18.<sup>16c</sup> However, stability of the dispersed droplets are not necessarily related to low interfacial tensions and high HLB values (see also, "Prevention of Redeposition: Possible Factors Involved" which are discussed later).

#### *Poor Correlation with Surfactant Properties*

Poor correlation of surfactant effectiveness with the surfactant properties listed was observed among the nonionic surfactants in Class A, and more so on comparison of the nonionics in Class A versus those in Class C. Although, incomplete surfactant properties data of the surfactants in Class C have limited the extent of the analyses, some examples of the anomalies are as follows:

1. Among the nonionics in Class A (Table 10), the surfactant effectiveness of Poly-Tergent SL-62 was not improved relative to Renex 678, in spite of the lower surface tension, lower interfacial tension, and faster rate of wetting of SL-62.
2. Little or no removal of MST-D from the origin of application was exhibited by Silwet L-7607 (Class C, Table 12) despite its excellent wetting properties and high HLB value. This anomaly was further emphasized on its comparison with the anionic and nonionic surfactants in Class A.

#### *Possible Explanation of the Anomalies*

In the cases cited, the poor correlation of surfactant effectiveness with wetting and emulsification properties indicates other factors may be involved. Possible factors include the role of solubilization<sup>17,18</sup>. This involves the spontaneous take-up of water-insoluble substances, such as oils, within the micelles of the surfactant. In this way<sup>17,18</sup>, non polar type materials are removed from the substrate. The possibilities of a solubilization mechanism being operative in the systems studied are described in the following analogies:

1. Solubilization occurs to a higher extent with oils that contain polar constituents<sup>19a</sup> such as fatty acids, esters, etc., (cf. methyl salicylate which, like the chemical agents, can be described as a polar oil<sup>20</sup>).
2. Solubilization is facilitated by the use of a surfactant concentration that is greater than its critical micelle concentration (cmc)<sup>15c</sup>. Thus, the greater surfactant effectiveness of

Renex 678 (nonionic in Class A), versus Aerosol AY-65 and Aerosol AY-100 (anionics in Class B) may be related to Renex 678 being evaluated at a concentration level (2%) which was far greater than its cmc (.0077%); Aerosol AY-65 and Aerosol AY-100 were evaluated at concentration levels 1.3% and 2% respectively which were not much above their cmc values (.9 to 1.2%). This assumption can be examined in future studies.

3. Surfactants which exhibit high HLB values within the range 15-18 are classified as solubilizers<sup>16c</sup>. Thus, a solubilization mechanism may also contribute to the effectiveness of Triton GR-5M and Aerosol GPG (HLB, 14-20); likewise, to the efficacy of Aerosol MA-80, since it is described as a solubilizing agent (see Table 2). Furthermore, the ineffectiveness of the Class B nonionic surfactants may be due to their lower HLB values (12.7-13.6).

#### *Prevention of Redeposition: Possible Factors Involved*

Redeposition, which was exhibited by the Class B surfactants, is a complex phenomenon. As alluded to earlier, it is not necessarily related to the interfacial tension and HLB values. In the prevention of redeposition, the effect of the surfactant on the contaminant and the substrate may involve the following:

1. Development of a stable interfacial layer structure between the contaminant droplet and the aqueous phase. Thus, coalescence with other drops on nearby surfaces is inhibited. A possible mechanism involves the formation of liquid crystals.<sup>21</sup>

2. Adsorption of the surfactant on the substrate: Factors which may be involved include electrical forces of repulsion.<sup>1c,16d,22</sup>, the energy barrier<sup>19b,23</sup>, and the hydration barrier<sup>16d,19c</sup>, between the contaminant and the substrate.

#### **Effect of Synthetic Seawater (Aqueous Medium)**

The most promising anionic and blend of anionic and nonionic surfactants, as well as an effective nonionic (Class A, Table 10) were subsequently re-evaluated using synthetic seawater as the aqueous medium. The nonionic surfactant, Renex 678, was selected in preference to Renex 30 because of its higher cloud point (99.4°C versus 84°C for Renex 30) - hence greater solubility in high salt concentrations such as seawater. The results shown in Table 15, indicate the following order of surfactant effectiveness AFFF (3%) >> Renex 678 (2%) > Aerosol GPG (1%) > synthetic seawater.

Based on removal time, AFFF appears promising (3 min. at 3%) as a decon candidate with a thickened mustard stimulant in sea water applications. Although the surfactant effectiveness of AFFF and Renex 678 were unaffected in a synthetic seawater

medium versus tap water, the effectiveness of Aerosol GPG decreased eighteenfold in synthetic seawater. This decrease may be related to its poor solubility in water: Aerosol GPG exhibits 1.6% solubility in distilled water at 30°C and only 540 ppm calcium tolerance at .5% concentration. In future studies, Aerosol MA-80 (1.6% or above) should also be evaluated in a sea water medium because of its greater solubility in water.

#### **Effect of Pennzoil Grease (Contaminant)**

The most promising anionic and blend of anionic and nonionic surfactants as well as the most effective nonionic were also evaluated in the removal of a worse case contaminant e.g., Pennzoil grease (see Experimental-Materials). The results shown in Table 16, indicate only Aerosol GPG (1% in tap water) to be effective (surfactant effectiveness, 25 min.). Since neither AFFF nor Renex 30 were effective even after 45 min spray period, the results indicate that in addition to its excellent wetting and emulsification properties, Aerosol GPG may also exhibit better solubilization properties than AFFF or Renex 30. This is consistent with its solubility in non polar organic solvents (see Table 2).

#### **Effect of Ionicity, Concentration and Spray Temperature of the Surfactant**

##### **Evaluation**

The effect of these variables on surfactant effectiveness was examined using a 2<sup>3</sup> factorial design (for details, see Experimental, Systems Examined). As shown in Table 17, at 20°C, surfactant effectiveness increased with an increase in ionicity and concentration. However, at 40°C and high surfactant concentration, a negative temperature effect was observed with the nonionic surfactant i.e., its surfactant effectiveness decreased with increase in temperature. Under similar conditions, the anionic surfactant exhibited no change. Thus, in the systems studied, surfactant effectiveness did not increase with increase in temperature.

##### **Mechanism**

The increase in surfactant effectiveness with increase in concentration is consistent with a detergency mechanism. Thus, at the critical micelle concentration, wetting properties are optimized. Also, above the critical micelle concentration, removal via solubilization is facilitated as was discussed earlier (see Possible Explanation of the Anomalies).

The approximate tenfold increase in surfactant efficacy of the anionic versus the nonionic surfactant - is more likely due to the superior wetting, emulsification, and solubilization

properties of Aerosol GPG than to its ionicity. However, the role of ionicity would be better evaluated by comparing surfactants with similar surface active properties, but differing only in ionicity.

The effect of temperature on soil removal is not definitive<sup>24</sup>. However, the negative temperature effect of Renex 678 at the high concentration level, may be due to decreased surfactant adsorption with increase in temperature<sup>12c</sup>.

#### SUMMARY AND CONCLUSIONS

A method involving a recycling flow system was developed to evaluate candidate decon fluids for spray applications. The method offers the capability of evaluating various simulant/substrate/surfactant systems, and uses two detectors. In the removal of a thickened simulant for mustard, UV spectrophotometry offers the potential for monitoring both the amount of methyl salicylate removed, and the rate of removal, within a 10 min. spray period. However, problems of light scattering due to the presence of bubbles in the flow system and/or hazy surfactant solutions have limited the usefulness of this detection method. Nevertheless, because of the automated aspect of this detection system (i.e., the UV-VIS spectrophotometer is interfaced with a computer), resolving these light scattering problems would greatly enhance the usefulness of the method.

The visual detection method offers a more rigorous test of surfactant efficacy than UV spectrophotometry since it monitors total removal of the thickened methyl salicylate (i.e., via the use of a dye incorporated in the formulation, MST-D). However, the visual detection method cannot be used to measure the rate of removal. Nevertheless, in cases of incomplete removal, it is useful in visualizing problems of redeposition. The two detection methods therefore complement each other. In order to be consistent in the determination of surfactant effectiveness the surfactants were evaluated using the visual detection method. UV absorbance measurements were also used as supporting data when possible.

Consistent with a detergency system, effectiveness of the decon test fluid was found to be specific for the type of substrate, the contaminant, and the aqueous medium employed. Thus, on a high energy surface such as stainless steel, tap water, which was used as the reference, and synthetic seawater appear to be promising decon candidates with a thickened mustard simulant (removal time, ~ 1 min). On the low energy surface, Teflon, promising decon candidates with a thickened mustard simulant include: sodium dioctyl sulfosuccinate i.e. Aerosol GPG, and Triton GR-5M (1%) in tap water but not in synthetic sea water; sodium dihexyl sulfosuccinate i.e., Aerosol MA-80 (1.6% in tap water) and AFFF (3% dilution) in both synthetic seawater and

in tap water. The removal times of these surfactant solutions were within 1 - 3 mins. In tap water, the order of effectiveness was: sodium dioctyl sulfosuccinate > sodium dihexyl sulfosuccinate > AFFF. Moreover, with a worse case contaminant such as Pennzoil grease on a Teflon substrate, only sodium dioctyl sulfosuccinate (1% in tap water) was effective.

On a Teflon substrate, surfactant effectiveness increased with surfactants that exhibited a combination of increased wetting, emulsification, and solubilization properties (e.g., sodium dioctyl sulfosuccinate). In a seawater medium, surfactants must also exhibit a high cloud point and high tolerance to calcium. Alternatively, sequestering agents can be added to the detergent formulation. Furthermore, in the removal of a thickened mustard simulant from a Teflon surface, surfactant effectiveness did not increase with increase in temperature. The overall results indicate various detergency mechanisms to be operative on a Teflon substrate but not on stainless steel.

In conclusion, the results are promising. However, their specificity, as described, indicates further work is necessary. (See Recommendations and Future Work).

#### RECOMMENDATIONS AND FUTURE WORK

1. The decon candidates which were found to be promising with a thickened mustard simulant on a Teflon substrate, should be re-evaluated on other challenging substrates and surfaces, and with other contaminants. Examples of such substrates/surfaces include other low and high energy surfaces such as: Lucite, samples of materials used on ships' deck surfaces - before and after wear, as well as various forms of surfaces viz., painted, dry, wet, rough, smooth, porous etc.
2. In conjunction, the search for superior physical decon candidates should continue, especially so, should the present candidates prove ineffective in the challenging systems proposed above. Some suggestions for improving the efficacy of the surfactants are based on the properties of those surfactants which were found to be promising. Thus, obtain commercially, or prepare "in house", detergent formulations that exhibit a combination of the following properties:

Low surface tension: < 20 dynes/cm at 25°C

Low interfacial tension : < 2 dynes/cm at 25°C

Fast rate of wetting: Almost instant at <0.5% surfactant concentration

Low critical micelle concentration: < 0.01%

High hydrophile lipophile balance : ~20 (or experiment)

High Cloud Point: > 60°C

High calcium tolerance

Soluble in water, polar and non polar organic solvents.

Consequently, formulated detergents should contain the following:

Wetting agents

Emulsifiers

Sequestering agents for hard/sea water

Anti-redeposition agents or suspending aids to prevent redeposition of the removed contaminant.

Corrosion inhibitors

3. Investigate other physical decon systems such as micro-emulsions.

4. Select decon candidates that are compatible with hypochlorite and/or other detoxifiers.

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TABLE 1

Some Physical Properties of Mustard and Its Simulant  
 with Specific Reference to Physical Decon  
 in an Aqueous Medium

PROPERTY*	METHYL SALICYLATE	MUSTARD (HD)
Molecular weight	152.14	159
Melting point (°C)	-8.6	11
Boiling point (°C)	220-224	217
Solubility in water (%)	.067	.09 (22°C)
Surf Tension at 25°C (dynes/cm)	37.5	42.1
Contact Angle on Dry Surface: (deg)		
Teflon	46	63
White gloss polyurethane paint	<4	17

\*From Reference 3b with some corrections.

TABLE 2.  
ANIONIC SURFACTANTS EVALUATED  
**Sodium Dialkyl Sulfosuccinates**  
(listed in decreasing size of alkyl group)

Surfactant (concentrate)	Alkyl Group	Solubility in Water %	Solubility in Organic Solvents <sup>a</sup>	Applications Wetting Agent	Emulsifiers	Manufacturer
Aerosol GPG (70%)	octyl	1.6	soluble	✓ (excellent)	✓ (excellent)	American Cyanamid
Triton GR-5M (60%)	octyl	3-4	soluble	✓ (excellent)	✓ (excellent)	Rohm and Haas
Aerosol MA-80 (80%)	hexyl	34	soluble	✓	✓ <sup>b</sup>	American Cyanamid
Aerosol AY-65 (65%)	amyl	40	soluble <sup>c</sup>	✓ <sup>d</sup>	-	American Cyanamid
Aerosol AY-100 (waxy solid)	amyl	40	soluble <sup>c</sup>	✓ <sup>d</sup>	-	American Cyanamid

<sup>a</sup> Includes polar and nonpolar organic solvents, unless otherwise stated  
<sup>b</sup> Also solubilizing agent  
<sup>c</sup> Soluble only in polar organic solvents; sparingly soluble in non-polar organic solvents  
<sup>d</sup> With high electrolyte and calcium tolerance  
✓ Recommended use  
- Not stated

TABLE 3

## NONIONIC SURFACTANTS EVALUATED

**Alkyl Phenol Polyoxyethylene (POE) Ethers:**  
(listed in decreasing number of moles of ethylene oxide (EO) for the same alkyl phenol)

Surfactants	Average Moles EO	Solubility in Waters (cloud point)	Solubility in Organic Solvents <sup>b</sup> 1% solution	Applications Wetting Agent	Emulsi- fiers	Manufacturer
Nonylphenol POE: Renex 678c	15	soluble (99.4°C)	soluble	✓ d	✓	I.C.I. Amer- icas, Inc.
Tergitol NP-10	10.5	miscible (60-65°C) .5% soln	miscible	✓	✓	Union Carbide
Iconol NP-9	9	soluble (54°C)	-	✓	✓	BASF Wyandotte Corp.
Poly-Tergent B-300	9	soluble (58°C)	soluble	e	-	Olin Chemicals
Octylphenol POE: Triton X-100	10	miscible (63-69°C)	miscible	✓e	✓	Rohm and Haas

a Soluble below its cloud point

b Includes polar organic solvents, and aromatic solvents, but not aliphatic hydrocarbons such as kerosene or mineral oil

c No longer available

d Recommended for use at high temperatures and salt concentration  
e Used in the following detergent formulations: auto body wash, hand dishwashing, laundry, wallpaper remover, waterless hand cleaner

✓ Recommended use  
- Not stated

TABLE 4  
NONIONIC SURFACTANTS EVALUATED

**Alliphatic Alcohol Polyoxyethylene Ethers:**

Surfactants	Alcohol Group	Average Moles EO	Solubility in Waters (cloud point)	Solvents <sup>b</sup> 1% soln.	Applications	Manufacturer
			Organic		Wetting Emulsifiers Agent	
Renex 30	branched chain	12	soluble (84°C)	soluble	✓/c	I.C.I. Americas Inc.
Iconol TDA-8	tridecyl	8	soluble (43°C)	—	✓/d	BASF Wyanotte, Corp.
Poly-Tergent SL-62	linear	8 <sup>e</sup>	soluble (60-64°C)	soluble	-f	Olin Chemicals
Makon NF-12	linear	g	dispersible (12-15°C)	—	✓/h	Stepan Co.

a Soluble below its cloud point

b Includes polar organic solvents and aromatic solvents but not mineral oil  
c Outstanding detergent and wetting action at low concentrations in hard water, alkaline and acid solutions

d Noted for excellent rapid wetting properties, relatively low foaming, good detergency, and versatility as emulsifiers and solubilizers

e Also contains 3 moles propylene oxide

f Used in following detergent formulations: hand dishwashing, laundry, waterless hand cleaner.  
g Proprietary, also contains propylene oxide units

h Excellent wetting action and low foaming properties  
✓ Recommended use  
- Not stated

TABLE 5  
NONIONIC SURFACTANTS EVALUATED (CONT'D)  
Other Types of Polyoxyethylene Compounds:

Surfactants	Compound	Solubility in Water <sup>a</sup> (cloud point)	Organic Solvents <sup>b</sup> 1% solution	Applications Wetting Agent	Emulsifiers	Manufacturer
Tween 20	Polyoxyethylene (20) sorbitan monolaurate	soluble (-)	soluble	-	✓	I.C.I. Americas Inc.
Zonyl FSN (40% concn.)	Fluoro-ether <sup>c</sup>	>2% (-)	d	✓ excellent	-	DuPont
Silwet 17607	Co-polymer dimethylpolysiloxane <sup>c</sup>	soluble (50°C)	soluble	✓ excellent	-	Union Carbide
White Magic	Formulated <sup>e</sup>	-	-	-	-	Packed by Safeway Stores, Inc.

<sup>a</sup> Soluble in water below its cloud point

<sup>b</sup> Includes polar organic solvents and aromatic solvents only

<sup>c</sup> Proprietary

<sup>d</sup> Soluble only in alcohols but not in toluene

<sup>e</sup> Contains water softening agents: complex sodium phosphate and sodium carbonate; corrosion inhibitor: sodium silicate; for cleaning and prevention of water spots on glassware: nonionic surfactant and chlorine bleach; processing aid: sodium sulfate; and suds regulating agent.

✓ Recommended use  
- Not stated

TABLE 6  
DECON OF MST-O/TEF/RX 30 2%

TIME(MIN)	ABS	PRESS
0	.015	.765
.5	.023	.824
1	.039	.824
1.5	.054	.824
2	.093	.843
2.5	.123	.745
3	.185	.745
3.5	.255	.765
4	.34	.784
4.5	.424	.804
5	.548	.804
5.5	.641	.804
6	.71	.804
6.5	.764	.804
7	.826	.804
7.5	.849	.744
8	.864	.804
8.5	.872	.804
9	.88	.804
9.5	.88	.843
10	.88	.863
10.5	.888	.863
11	.88	.882
11.5	.872	.882
12	.849	.745
12.5	.833	.765
13	.833	.765
13.5	.826	.784
14	.826	.804
14.5	.826	.804
15	.818	.804

RUN #16 ON 2-7-85

SIMULANT = THICKENED METHYL SALICYLATE (VISC 5038 CS) WITH CELANTHRENE  
BRILLIANT DYE SPOTTED AT NOZZLE IMPACT (51.8 MB) OVER 4 SQ CM AREA

DECON IS RENEX 30 (2%) IN TAP WATER WITH SPRAY TEMP 21 DEG C

NOZZLE FULL CONE ABOUT 5 PSI WITH FLOW RATE ABOUT 600 ML/MIN

TABLE 7  
DECON OF MST-D/TEF/AFFF 3% (ANSUL)

TIME(MIN)	ABS	PRESS
0	.069	.863
.5	.154	.962
1	.417	.863
1.5	.602	.863
2	.664	.882
2.5	.772	.863
3	.741	.882
3.5	.779	.882
4	.803	.902
4.5	.772	.902
5	.81	.902
5.5	.818	.902
6	.864	.902
6.5	.857	.902
7	.895	.902
7.5	.88	.902
8	.972	.902
8.5	.996	.922
9	.926	.863
9.5	.942	.882
10	.957	.882
10.5	.949	.882
11	.849	.882
11.5	.926	.902
12	.857	.882
12.5	.934	.882
13	.903	.882
13.5	.949	.902
14	.926	.902
14.5	.918	.902
15	.849	.882

RUN #35 ON 3-5-85

SIMULANT = THICKENED METHYL SALICYLATE (VISC 5038 CS) WITH CELANTHRENE  
BRILLIANT DYE SPOTTED AT NOZZLE IMPACT (50 MG) OVER 4 SQ CM AREA

DECON IS AFFF 3% EX 3% CONCENTRATE (ANSUL) IN TAP WATER WITH SPRAY TEMP 25 DE  
G C

NOZZLE FULL CONE ABOUT 5 PSI WITH FLOW RATE ABOUT 6000 ML/MIN

TABLE 8  
Experimental Design: 2<sup>3</sup> Factorial<sup>a</sup>

<u>Independent Variables</u>	<u>Levels</u>	
	<u>Zero-Low</u>	<u>High</u>
Ionicity	Nonionic <sup>b</sup>	Anionic <sup>c</sup>
Concentration (%)	0.05	1-2
Spray Temperature (°C)	20	40

<sup>a</sup> Refers to 3 independent variables studied at 2 levels.

<sup>b</sup> Renex 678: polyoxyethylene (15) alkyl aryl ether

<sup>c</sup> Aerosol GPG: dioctyl sodium sulfosuccinate

TABLE 9

**Stainless Steel Substrate: Effect Of Surfactants vs. Water -**  
 for ~100% Removal of MST-D at 5 psi Spray Pressure and  
 ~21°C: Surfactant Properties and Removal Time

Surfactants	Surface Tension dynes/cm <sup>a</sup> (concn)	Interfacial Tension <sup>a</sup> in sec dynes/cm <sup>a</sup> (concn)	Wetting <sup>b</sup> at 25°C (concn)	CMCC %	HLB <sup>d</sup>	Surfactant Concn in Tap Water %	Removal Time min.
Renex 30	28 (.01%)	8 (.01%)	25 (.04-.06%)	~.01	14.5	2	1.5
Aerosol GPG	26 (.5%)	1.97(1%)	<.2 (.5%)	.1	14-20	1	3.5
AFFP (National)	15.8 (3%)	3 (3%) <sup>e</sup>	-	-	-	3	~7
White Magic	-	-	-	-	-	.2	.75
Reference:						.1	.9
Tap Water						0	1
Synthetic						0	.75
Seawater							

<sup>a</sup> Measurements made vs Nujol mineral oil unless otherwise stated

<sup>b</sup> Draves Wetting Test

<sup>c</sup> Critical micelle concentration

<sup>d</sup> Hydrophile lipophile balance; HLB values<sup>16c</sup> for: emulsifiers, 8-18; detergents, ~ 13-15; solubilizers, 15-18

<sup>e</sup> Measurements made vs cyclohexane  
 - Not available

TABLE 10  
**Teflon Substrate: Class A Surfactants - Effect of ~100% Removal of MST-D**  
 from the Entire Test Surface, at 5 psi Spray Pressure and  
 ~21° C: Surfactant Properties and Removal Time

Surfactants	Surface Tension dynes/cm (concn)	Interfacial Tension <sup>a</sup> dynes/cm (concn)	Wetting in sec at 25°C (concn)	CMC <sup>b</sup> %	HLBC	Surfactant Concn in Tap Water %	Removal Time min.
<u>Anionics:</u>							
Aerosol GPG	26 (.5%)	1.97 (1%)	<.2 (.5%)	.1	14-20	1	1
Triton GR-5M	27 (.1%)	1 (.1%) <sup>d</sup>	5 (.2%)	—	—	1	.9
Aerosol MA-80	27.8 (1%)	4.2 (1%)	10 (.3%)	1.2-1.6	25-30	1.6	1.5
<u>Cationics:</u>							
G-263	—	—	—	>30	.5	4.5	
G-271	—	—	—	25-30	.5	5.6	4

TABLE 10 (cont'd.).

Surfactants	Surface Tension dynes/cm (concn)	Interfacial Tension dynes/cm (concn)	Wetting in sec at 25°C (concn)	CMC <sup>b</sup> %	HLB <sup>c</sup>	Surfactant Concn in Tap Water %	Removal Time min.
<u>Nonionics:</u>							
Renex 678	33 (.01%)	7 (.01%)	25 (.3-.5%)	.0077	15	2	10
Renex 30	28 (.01%)	8 (.01%)	25 (.04-.06)	~.01	14.5	1	10.7
Poly-Ferment SL-62	29 (.1%)	4 (.1%)	Instant (.5%)	—	14	1	10.7
<u>AFFF Blends:</u>							
National	15.8 (3%)	3 (3%) <sup>e</sup>	—	—	—	3	~3
Ansul	16-17.5 (3%)	1.4-1.8 (3%) <sup>e</sup>	—	—	—	3	~3
3M	16.5 (3%)	3.3 (3%) <sup>e</sup>	—	—	—	3	~2.5
<u>None (Reference):</u>							
Tap Water	72	52 <sup>f</sup>	—	0	>15 <sup>g</sup>		

<sup>a</sup> Measurements were made vs Nujol mineral oil, unless otherwise stated

<sup>b</sup> Critical micelle concentration

<sup>c</sup> Hydrophilic lipophile balance; HLB values<sup>16c</sup> for: emulsifiers 8-18; detergents, 13-15; solubilizers, 15-18

<sup>d</sup> Measurements were made between iso octane/synthetic brine

<sup>e</sup> Measurements were made vs cyclohexane

<sup>f</sup> Measurements were made vs Arcoprime 90 mineral oil

<sup>g</sup> UV absorbance data indicated ~50% removal of methyl salicylate

— not available

TABLE 11

**Teflon Substrate: Class B Surfactants - Effected Incomplete Removal of MST-D from the Entire Test Surface at 5 psi Spray Pressure and ~21°C: Surfactant Properties and Removal Time From Origin: Degree of Redeposition (after 15 min Spray Period)**

Surfactants	Surface Tension dynes/cm (concn)	Interfacial Tension <sup>a</sup> dynes/cm (concn)	Wetting in sec	HLB <sup>b</sup> (concen)	Surfactant Concen in Tap Water %	Removal Time from Origin Only min	Degree of Redeposition
<b>Anionics:</b>							
Aerosol AY-65	29.2 (1%)	7 (1%)	14 (.55%)	35 <sup>c</sup>	1.3	~15	++ to +++
Aerosol AY-100	29.2 (1%)	7 (1%)	14 (.55%)	35 <sup>c</sup>	2	~15	++ to +++
<b>Nonionics:</b>							
Triton X-100	30 (1%)	1 (1%) <sup>c</sup>	10 (.092%)	13.5	2	~ 8	++
Zonyl FSN	23 (.1%)	-	-	-	.8	~13	++ to +++
Tergitol NP-10	31 (.1%)	-	2 (.2%)	13.6	2	~14	+++
Iconol TDA-8	-	-	-	12.7	3	~14	+++
Poly-Tergent B-300	29 (.1%)	3 (.1%)	3 (.5%)	12.9	2	~15	+++
<b>Blend</b>							
<u>Bio-soft</u>	-	-	-	-	4	11	+
HD-100	-	-	-	-	-	-	-

<sup>a</sup> Measurements were made vs Nujol mineral oil unless otherwise stated

<sup>b</sup> Hydrophile-lipophile balance

<sup>c</sup> Measurements were made vs Arcoprime 90 mineral oil

+++ > ++ > +  
- Not available

TABLE 12

**Teflon Substrate: Class C Surfactants Nonionics that Effected Little/No Removal of MST-D from the Origin of Application During 15 Min Spray Period at 5 psi and ~21°C: Surfactant Properties and Methyl Salicylate Absorbance Values at 10 Min Spray Period**

Surfactants (2% in Tap Water)	Surface Tension dynes/cm (concn)	Interfacial Tension <sup>a</sup> dynes/cm (concn)	Wetting in sec (concn)	HLB <sup>b</sup>	Absorbance <sup>c</sup>
Tween 20	36 (.1%)	6 (.1%)	-	16.7	.41
Hakon NP-12	34 (.1%)	-	-	-	.64
Iconol NP-9	32 (.1%)	-	-	1.3	.47
Silwet L-7607	22.4 (1%)	-	2.4 (.25%)	17	.36
None: Reference					
Tap Water	72	52d			.43

<sup>a</sup> Measurements were made vs Nujol mineral oil

<sup>b</sup> Hydrophile lipophile balance

<sup>c</sup> Absorbance of methyl salicylate at 304 nm

<sup>d</sup> Measurements were made vs Arcoprime 90 mineral oil

TABLE 13  
DECON OF MST-O/TEF/THN-20 (2%)

TIME(MIN)	ABS	PRESS
0	.015	.941
.5	.039	.882
1	.062	.843
1.5	.093	.863
2	.1	.843
2.5	.131	.882
3	.162	.902
3.5	.193	.922
4	.201	.922
4.5	.224	.941
5	.247	.941
5.5	.27	.961
6	.278	.981
6.5	.301	.961
7	.309	.941
7.5	.332	.941
8	.347	.941
8.5	.417	.961
9	.386	.941
9.5	.417	.961
10	.409	.961
10.5	.432	.961
11	.448	.922
11.5	.455	.922
12	.471	.902
12.5	.471	.922
13	.494	.922
13.5	.509	.922
14	.509	.941
14.5	.525	.922
15	.517	.941

RUN #44 ON 3-7-85

SIMULANT = THICKENED METHYL SALICYLATE (VISC 5038 CS) WITH CELANTHRENE  
BRILLIANT DYE SPOTTED AT NOZZLE IMPACT (50 MG) OVER 4 SQ CM AREA

DECON IS I.C.I. AMERICAS INC TWEEN 20 (2%) IN TRP WATER WITH SPRAY TEMP 23 DE  
G C

NOZZLE FULL CONE ABOUT 5 PSI WITH FLOW RATE ABOUT ABOUT 600 ML/MIN

TABLE 14  
DECON OF MST-D/TEF/TAP WATER

TIME(MIN)	ABS	PRESS
0	.023	.922
.5	.085	.941
1	.162	.961
1.5	.208	.981
2	.239	.961
2.5	.255	.981
3	.27	1.02
3.5	.286	1.039
4	.301	1.059
4.5	.324	1.098
5	.332	1.118
5.5	.347	1.059
6	.355	1.079
6.5	.386	1.079
7	.386	1.079
7.5	.401	1.098
8	.401	.922
8.5	.424	.922
9	.44	.922
9.5	.448	.922
10	.463	.882
10.5	.455	.902
11	.463	.882
11.5	.463	.882
12	.478	.863
12.5	.494	.824
13	.471	.863
13.5	.478	.843
14	.502	.863
14.5	.509	.882
15	.517	.882

RUN #48 ON 3-14-85

SIMULHNT = THICKENED METHYL SALICYLATE (VISC 5038 CS) WITH CELANTHRENE  
BRILLIANT DYE SPOTTED AT NOZZLE IMPACT (50 MG) OVER 4 SQ CM AREA

DECON IS TAP WATER AS CONTROL IN TAP WATER WITH SPRAY TEMP 21 DEG C

NOZZLE FULL CONE ABOUT 5 PSI WITH FLOW RATE ABOUT 600 ML/MIN

TABLE 15

## Effect of Synthetic Seawater on Surfactant

Effectiveness: Removal of MST-D from a Teflon  
 Substrate at 5 psi Spray Pressure and ~21°C

<u>Surfactants (concen in synthetic seawater)</u>	<u>Removal Time (min)</u>
National AFFF (3%)	3
Aerosol GPG (1%)	18
Renex 678 (2%)	10
Reference: Synthetic Seawater	>15

TABLE 16

## Effect of Contaminant on Surfactant Effectiveness:

Removal of Pennzoil Grease from Teflon:

5 psi Spray Pressure and ~21°C.

<u>Surfactants (concen in tap water)</u>	<u>Removal Time min</u>
Aerosol GPG (1%)	25
National AFFF (3%)	>45
Renex 30 (1.5%)	>45
Reference: Water	>45

TABLE 17

## Teflon Substrate: Effect of Ionicity, Concentration and Spray Temperature of Surfactant on Surfactant Effectiveness

Surfactant (Ionicity)	Concentration %	Temperature °C	Removal Time (min)
Aerosol GPG (Anionic)	.035	20	>15
	.035	40	>15
	1	20	1
	1	40	1
Renex 678 (Nonionic)	.05	20	>15
	.05	40	>15
	2	20	10
	2	40	>15
Reference: Water	0	20	>15
	0	40	>15

END

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